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ORIGINAL RESEARCH

THE RELATIONSHIP BETWEEN PASSIVE GLENOHUMERAL TOTAL ROTATION AND THE STRENGTH OF THE INTERNAL AND EXTERNAL ROTATOR MUSCLES, A PRELIMINARY STUDY

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ABSTRACT

Background: There is little research on how the amount of shoulder joint range of motion, specifically glenohumeral rotation, may be related to the muscle strength of the rotator cuff muscles. A long held belief is that a joint with excessive range of motion needs sufficient muscular strength for stability. However, no studies have examined this concept.

Purpose: The purpose of this study was to see if total arc of glenohumeral joint rotation (External rotation [ER] + Internal rotation [IR]) could predict peak isometric muscle strength of the IR or ER muscles of the shoulder.

Study Design: Cross-sectional study design

Methods: Fifty-three participants (41 females, 12 males) participated in the study. Passive glenohumeral joint internal rotation and external rotation motion was measured for each participant with a standard goniometer. Isometric muscle force of the ER and IR muscles were tested using a handheld dynamometer in three positions: end range ER, neutral 0°, and end range IR. Data were analyzed using a non-parametric tree based regression method (CART) and then cross-validated.

Results: The results showed that those with an increased total arc of motion of glenohumeral rotation (greater than 165.0°) had less muscle isometric muscle strength in all tests positions than those with less glenohumeral rotation.

Conclusion: Decreased force of the ER and IR muscles of the shoulder was noted in those with increased total arc glenohumeral rotation (> 165.0°), specifically those with increased glenohumeral internal rotation (> 80.0°) when compared to those with glenohumeral rotation (< 165.0°) and glenohumeral internal rotation (< 80.0°). Future studies should include more males and attempt to develop strategies to assist those with larger excursions of shoulder rotation who may be at risk of developing shoulder problems.

Level of Evidence: Level 2

Keywords: Classification and regression tree, range of motion, rotator cuff, shoulder

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INTRODUCTION

Increased range of motion at the glenohumeral joint is often related to glenohumeral joint instability.[1,2] When too much passive joint movement is found at a joint susceptibility to subluxation is often noted.[3] A number of different common shoulder problems are related to excessive glenohumeral joint range including glenoid labrum lesions, subluxation, and dislocation.[1,2,4] Cyriax notes that a joint with capsular laxity, whose stability is not under full muscular control, often displays excessive range of motion.[3] The rotator cuff muscles provide dynamic stability and thus the muscular control to the glenohumeral joint diminishing the stress on the glenohumeral joint capsule and ligaments thus reducing the risk of injury.[5][6] Contraction of the rotator cuff muscles tightens the joint capsule and provides compression to the joint thereby decreasing humeral head translation.[7] Clinically, the stabilizing role of the rotator cuff is evident in those with rotator cuff tears where a damaged rotator cuff can contribute to glenohumeral joint instability.[8] Thus assessing the total arc of glenohumeral rotation as well as the strength of the rotator cuff muscles is important to physical therapists, however, whether the two are related remains unknown.

Many researchers have examined the strength of the shoulder ER and IR muscles using isometric or isokinetic methods, however, none have looked at how strength is related to joint ROM. Few if any studies in the literature have examined whether the amount or type of glenohumeral rotation is related to the strength of the rotator cuff muscles. Specifically, could the amount of glenohumeral rotation, or total arc of motion (IR + ER) predict the strength of the rotator cuff muscles (ER and IR)? Most of the studies published have used isokinetic testing methods demonstrating similar results, mainly that the ER muscles are weaker than the IR muscles, the dominant side is stronger than non dominant side for the IR muscles (especially in athletes who regularly use one side more than the other), and women are weaker than men, but none have collected data on how rotator muscle strength relates to shoulder range of motion. [9,10] Donatelli examined shoulder range of motion and strength of the ER and IR muscles in 39 professional baseball players, however in their study they did not look at how or if differences in glenohumeral rotation were related to the isometric strength of the IR or ER muscles.[11] No previous study has looked at how passive shoulder range of motion (specifically glenohumeral) is related to the strength of the IR and ER muscles when divided into groups with differences in their total arc of glenohumeral rotation.

The purpose of this study was to see if total arc of rotation of the glenohumeral joint rotation (ER + IR) could predict peak isometric muscle strength of the IR or ER muscles of the shoulder. Specific questions posed included: 1) Do those who exhibit larger total arcs of glenohumeral rotation have IR or ER muscle strength differences? 2) Where in the range of motion (e.g. middle range versus end ranges of glenohumeral rotation) do the differences in ER or IR muscle strength occur? The research hypothesis for this study was that the IR and ER muscles of those with an increased total arc of shoulder glenohumeral rotation would have reduced or less isometric strength at the end range of motion of the ER and IR muscles when compared to those with subjects who did not have an increased total arc of glenohumeral rotation.

METHODS

This study represents secondary analysis of data from 53 adult participants who were recruited as part of a cross-sectional study that was previously approved by the Maryville University Institutional Review Board. The participants included a sample of convenience from Maryville students (both athletes and non-athletes) and from the surrounding St. Louis area. The sample consisted of 12 males and 41 females age 18-65 (mean age: 24.1; SD: 9.2). Forty-nine participants were right hand dominant and four were left hand dominant. Participants were asked to wear non-restrictive clothing with access to the shoulder (i.e. a loose fitting t-shirt). Exclusion criteria included: previous shoulder surgery in the past three years, shoulder pain, neck pain, arm pain, unable to tolerate the supine position, history of chronic shoulder dislocations, or current pregnancy. Participants all signed an informed consent form, filled out a questionnaire to assess if they were eligible for the study, and were then assigned a research participant number. The participant number was used to determine which muscle group would be tested first

at each position; even number participants had the ER muscles tested first, and odd numbers had the IR muscles tested first. Next, participants randomly drew cards to determine whether the right or left arm was tested to prevent the problem of statistical independence by using both shoulders in a single subject. All together 28 right shoulders and 25 left shoulders were tested. Participants then selected different cards, each with a different testing position (end range IR, end range ER, and neutral), to randomize the testing position order.

A twelve-inch plastic universal goniometer was used to measure passive shoulder IR and ER range of motion (ROM); standard error of the measure for a universal goniometer is five degrees.[30,31] The ROM of shoulder (glenohumeral) rotation was measured with the participant lying supine on a standard treatment table, with the glenohumeral joint positioned at 90° of abduction for passive IR and ER measurments. Participants were first passively moved through their available shoulder rotation ROM prior to the ROM measurements, this was performed primarily to assess the participant's ability to relax during ROM testing. Manual pressure was applied to the anterior shoulder (caracoid process) using a method described by Cibulka[12] in order to prevent substitution at the sternoclavicular and acromioclavicular joints while the glenohumeral joint was rotated into the direction of IR or ER until a firm end feel was met, (Figure 1) as a firm end feel represents the end PROM for each movement about the glenohumeral joint. The goniometer was aligned as follows: the axis at the olecranon process, the stationary arm was perpendicular to the floor, and the moving arm was aligned with the ulna using the ulnar styloid process for reference. A small towel roll was placed under the participant's distal humerus so that it remained parallel to the treatment table surface. Goniometric measures for IR and ER were measured and a different observer documented the ROM. Intra rater reliability using the intraclass correlation coefficient (ICC) was established from the first consecutive 15 participants. The ICC (3,1) for both IR and ER was found to be high, ICC = .99 [95% CI: .97-.99]. The minimal detectable change (MDC_{95}) was determined for IR ROM (4.7°) and ER ROM (3.4°) using the formula $MDC_{95} = SEM \times 1.96 \sqrt{2}$. All descriptive data for our participants ROM is displayed in Table 1.

Table 1. *Glenohumeral passive rotation range of motion measurements, in degrees.*

	Minimum	Maximum	Mean	Sd
ER ROM	60	112	90.64	12.26
IR ROM	19	89	55.66	17.07
Total ROM	103	188	146.3	17.43

Shoulder strength during manual muscle testing (MMT) was defined as the peak isometric force measured with a hand held dynamometer (HHD) (Hoggan Scientific, Salt Lake City, UT). Both IR and ER isometric strength was measured using a HHD by performing a "make" test of the IR and ER muscles with the participant lying supine The two testers who performed the MMT were different from the ROM testers and were blinded from the ROM data. The "make" test using a HHD has previously been demonstrated with an ICC of .91.[13] Participants strength was assessed in three different test positions: end range ER, neutral 0° and end range IR. The end range IR and ER positions consisted of the end of the each participant's available ROM in each direction without scapular or trunk substitutions. The glenohumeral neutral 0° position was where the participant's forearm was placed perpendicular to the anatomical axis of the body While supine the participant was manually placed, according to their range, in each of the different test positions prior to strength testing. The HHD was placed approximately three cm proximal to the ulnar styloid process, and in the center of the participant's forearm, while a slight pressure was used to stabilize the anterior shoulder to prevent scapular substitution. All participants were instructed to slowly increase their force into the HHD until a maximum contraction was achieved. This maximum contraction was held for three seconds. Each participant had IR and ER isometric strength measurements taken twice at each testing position and then averaged, and the same muscle group was never assessed consecutively. To ensure data were taken in an unbiased manner, the measures were read and recorded by a separate observer. All isometric strength data was normalized to body weight by dividing muscle force in Newton's by body weight in kg (N/kg). MDC_{95} for normalized ER isometric muscle force was determined using the formula $MDC_{95} = SEM \times 1.96 \times \sqrt{2}$; $MDC_{95} = .055$ N/

Table 2. *Reliability (ICC's) for IR and ER MMT for each test position.*			
	End-range IR	**Neutral 0°**	**End-range ER**
External rotator muscles	0.980	0.987	0.952
Internal rotator muscles	0.990	0.978	0.991

kg. The MDC$_{95}$ for normalized IR isometric muscle force was also determined; MDC$_{95}$ = .063 N/kg.

The reliability of the "make" manual muscle tests for the first 15 participants IR and ER muscles for each of the different test positions was very high (.95-.99) (Table 2). The principal investigator did not participate in the collection of any data and was also blinded to the results until all of the data was gathered (ROM and MMT).

Statistical Analysis
A non-parametric classification and regression tree (CART) based method that uses a recursive partitioning process from the open source statistical package **R**[14] was used to analyze the data. The CART routine begins with a binary split using a multiple regression method that looks for the greatest deviance (mean squared error) between the independent variable or predicted variable (shoulder ROM) and the predictors (either ER or IR muscle strength) to find the best fit.[14] The CART program creates binary splits, thus always splitting the data into two groups (nodes) creating the "best" splits maximizing the difference between the two (binary) groups.[15] The process stops when there is one observation per node (group) or the node has identical predictor variables.[15] An advantage of using CART program is that it can specifically identify if there is a threshold or pattern of glenohumeral rotation that could predict weakness of the IR and ER muscles. A total of 6 different CART trees were modeled using shoulder strength data of the ER and IR muscles at the three different muscle test positions: end range ER, end range IR, and mid-position (0° - neutral) as the dependent variable. The independent variable was total glenohumeral rotation range of motion (IR + ER) for all six CART trees modeled. An inherent limitation of CART models is that they can have high variance, therefore, cross-validation was performed to "prune the tree" or "trim back the tree" in order to determine the best fit–followed by the use of a bootstrap procedure (1,000 resamples with replacement) to ensure data accuracy.[14] Data were also examined by looking at the means and standard deviations by group created by the tree methods splitting at the first node. (Table 3 & 4)

RESULTS
The results indicated that the best predictor for ER and IR muscle strength was when total shoulder rotation (ER + IR) was "split" at 165.0° creating a subgroup (N = 9) who had total shoulder ROM greater than 165° and another with total shoulder ROM less than 165° (N = 44), thus creating two groups. Participants with total glenohumeral rotation greater than 165.0°, regardless of whether they were tested at the end range or neutral position of external and internal rotation, had weaker ER and IR muscle force than those who had total shoulder ROM less than 165°. (Table 3 & 4)

Six females and 3 males had a total ROM (ER + IR) that exceeded 165.0° (range: 166.5-187.0°; sd = 6.8) [CI$_{95}$: 166.8-174.5]. The mean amount of passive ER was 91° (range: 81-110; sd = 9.8) [CI$_{95}$: 88.0-99.1] while

Table 3. *Mean (SD) Isometric External Rotator muscle strength in N/kg for the 2 groups.*			
Group	**ER**	**N**	**IR**
Total ROM > 165.0	.20 (.06)	.63 (.10)	.45 (.20)
Total ROM < 165.0	.30 (.08)	.71 (.19)	.63 (.10)
ER = end range ER; IR = end range IR; N = Neutral 0°			

Table 4. *Mean (SD) Isometric Internal Rotator muscle strength in N/kg for the 2 groups.*			
Group	**ER**	**N**	**IR**
Total ROM > 165.0	.43 (.09)	.54 (.10)	.35 (.10)
Total ROM < 165.0	.60 (.28)	.61 (.21)	.42 (.14)
ER = end range ER; IR = end range IR; N = Neutral 0°			

the mean amount of passive IR was 81° (range 74-88°; sd = 11.7) [CI₉₅: 74.0-88.0]. For the 44 participants who had total shoulder ROM less than 165.0° their mean passive ER was 90° (range 60-112°; sd = 12.6) while mean passive IR was 50° (range 19-83°; sd = 13.1).

DISCUSSION

The CART analysis showed that those participants whose total arc glenohumeral rotation exceeded 165.0° both the IR and ER muscles exhibited less force production than those whose glenohumeral rotation was less than 165.0°. This was true for all test positions (end range IR, end range ER, and the neutral position). The isometric strength values exceeded minimal detectable change (MDC₉₅) for both the ER and IR muscles in all test positions when comparing the group with greater than 165.0° of total arc of rotation with those who had less than 165.0° of rotation (Tables 3 & 4). Although the CART method established a cutoff value (165.0°) that split the groups into two, the exact break point is not the most important point, as different samples may show different cutoff points. The results of this study indicate that participants with a greater total arc of glenohumeral rotation exhibited ER and IR muscle weakness when compared to those with smaller total arc of glenohumeral rotation.

The amount of range of motion for IR and ER in the glenohumeral joint is dependent on a number of different variables including gender, dominant arm (predominantly in overhead throwers), active versus passive movement, and scapular stabilization method (for IR). Data from studies by Boon et al and Awan et al show that males have overall less total glenohumeral rotation than females, with less IR and ER motion.[16] [17] The data from other studies show only a small difference (most studies about 4°; less than MDC) between dominant arm versus non-dominant arm.[16] [18,19] [17,20] However the range of motion values for glenohumeral joint rotation of overhead throwers (primarily baseball pitchers) are significantly different when comparing dominant to non-dominant side.[21] In overhead throwers IR is often less than ER and with increasing age and participation the difference between IR and ER becomes greater.[22,23] [24] Often overhead throwers have a reduction in IR on the dominant shoulder side.[23,25] None of the participants were involved in an overhead throwing

sport (e.g. baseball) so there was no expectation to see meaningful differences between in IR and ER rotation range of motion between the dominant side and non-dominant side. In this study, however, differences due to dominance were not evaluated since only one shoulder was tested and the shoulder was randomly selected.

In this group of participants the data showed that the larger excursion in glenohumeral range of motion was perhaps due to a larger than expected amount of glenohumeral joint IR. Those with a total glenohumeral PROM greater than 165.0° had a mean IR of 81° while the mean of those with PROM less than 165.0° had a mean IR of only 50°. In a recent study that examined the quantity of shoulder rotation only 5% of the females and males had IR values greater than 80°.[18] As an individual ages the total amount of glenohumeral rotation decreases,[18] however in the current study only a young cohort was represented (mean age 24).

The amount of glenohumeral IR measured is dependent upon how the scapula is stabilized. Care must be taken when looking at other studies whose authors did not stabilize the scapula. Studies that do not include any scapular stabilization allow motion at the acromioclavicular and sternoclavicular joints [12] thereby inflating the values of passive glenohumeral IR by as much as 30°.[16] In this study we stabilized the scapula by firmly holding the coracoid process, using a method described by Cibulka,[12] in an effort to allow only glenohumeral joint motion to occur. Data from studies that collected data on glenohumeral IR measurements using a similar cohort and stabilization method found that glenohumeral IR ROM ranged anywhere from 33° to 73° with a mean amount of passive of IR about 55°.[19,26 16,27-30]

An important aim of this study was to determine whether ER and IR muscle force was different at end of range because that is where the greatest stress on joint capsule, labrum and ligaments develop and most injuries likely occur. Escamilla suggests that most shoulder injuries occur during the end phases of throwing where shoulder forces, torques and muscle activity are generally greatest during the arm cocking and arm deceleration phases of overhead throwing.[31] During overhead throwing, high rotator cuff muscle activity is generated to help resist the

high shoulder distractive forces occurring during these phases. The external rotators must contract to decelerate medial shoulder rotation during the release or follow-through phase of throwing, while the internal rotators must contract to decelerate lateral rotation during the cocking phase of throwing. Previous authors have shown that isometric peak force of the shoulder ER muscles is lowest when the ER muscle's are at end range ER, and the IR muscle force production is lowest when at end range of IR.[32] Therefore, those with larger excursions of glenohumeral rotation may be more vulnerable to throwing injuries because of weakness in their rotator cuff muscles especially end ranges of IR and ER, however future studies are needed. Physical therapists should MMT the shoulder at more than just the commonly taught standard positions to identify those who may be more vulnerable in the end ROM positions.

A nonparametric Classification and Regression Tree (CART) method was used to analyze the data. An important advantage of using the CART over standard statistical analysis is that groups of variables can be subdivided or classified into groups that reflect patterns that allow for meaningful clinical decision-making.[15] So far many authors have examined shoulder range of rotation and isometric muscle strength but in all of these studies the data was combined into one group. Using standard statistics to examine data it is likely that meaningful information may never have been uncovered. The CART algorithm often works well because it often classifies groups into clinically important categories.[15] In this study the binary splitting created two groups with different total arcs of glenohumeral rotation that displayed different isometric muscle strength. Without using a program like CART it would have been unlikely to uncover such differences.

This study is a preliminary study; a limitation of this study is the relatively small sample size (N = 53). Small sample sizes can lead to misclassification when using CART. To adjust for this two methods were utilized, one was to cross-validate the results (which simplified the results by pruning the branches of the tree) and secondarily, a "bootstrap" was used to resample with replacement the original data (1000 times). Using convenience sampling may also have resulted in a distorted assembly, thus replication of the study is important with future studies performed

to validate this studies results. There were more females than males (41 females versus 12 males) and three males had large total glenohumeral rotation excursions compared to six females. Previous studies have found that females have a slightly larger excursion of shoulder rotation.[17,18,33,34] To make sure this gender imbalance did not affect the results we modeled (CART) using female and male data separately resulting in the same cutoff threshold for total glenohumeral rotation (165.0° of total glenohumeral ROM) with a mean of IR ROM (80.0°). Furthermore to prevent the potential problem of minority outliers to bias the sample resampling was performed for the gender-separated data using the bootstrap method (resampling 1000 times) and no significant differences were found. Regardless, future studies that would replicate this study using a larger sample size are needed to substantiate this studies findings.

CONCLUSION

When assessing shoulder strength of the ER and IR muscles particular attention should be paid to those who have increased total arc of PROM of glenohumeral rotation (> 165.0°), especially in those with large amounts of IR ROM (80° or greater). Those with increased glenohumeral internal rotation (> 80°) generate less peak isometric IR and ER strength throughout their range of rotation than those with glenohumeral internal rotation under 80°.

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